Exam in the course Diagnostic Imaging - SSY 186
Date: 2015-05-30, Time: 08.30-12.30

Exam type:	Closed book – Only the specified materials are permitted.
Permitted materials:	Calculator, dictionary, drawing materials (e.g. compass, ruler).
Questions:	Artur Chodorowski, 073-5543777 Andreas Fhager, 076-1257012
Exam script viewing:	Time and place will be announced by email when the results are published.
Important:	All answers must be written in English.

OBS!

- Answer all 5 (five) questions.
- Each is worth 20 marks. (5 x 20 = 100 marks, maximim)
- Each question consists of multiple parts.

Examination ID number:……………………………….

Question 1 – Magnetic Resonance Imaging (20p)

(1)
(a) Write the Larmor equation.
(b) Explain what the equation expresses (i.e. translate the mathematical formalism into prose).
(c) Describe the components of the equation (physical quantities and constants, units).

(5 p)

(2) The magnetization of hydrogen nuclei provide the source of signal for clinical MRI and the pulse sequence defines the scanning scheme. The two different relaxation processes for the nuclear magnetization are a main contribution to MR image contrast.

(a) Which relaxation process provided the contrast when cerebro-spinal fluid in the ventricles in the brain appears darker than brain tissue (white matter and grey matter) in the MR image?

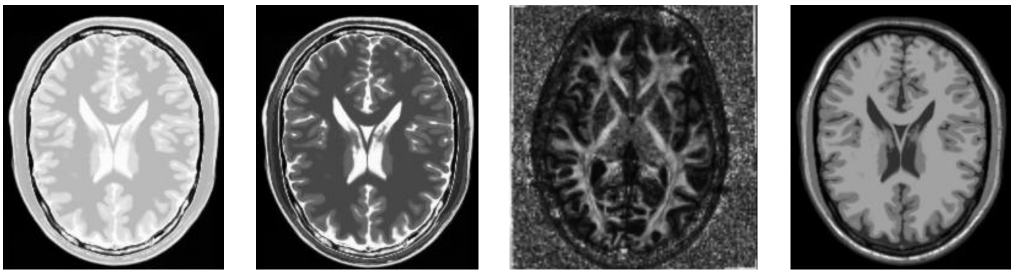
(b) Which component of the nuclear magnetization does the relaxation process in a) apply to?

(c) Give the two pulse sequence timing parameters that affect the basic MR contrast (symbol, name and unit).

(d) State (qualitatively) how these parameters should be chosen to produce the image contrast in (a). Motivate this choice.

(10 p)

(e) The images below show four different images of a slice through the skull, as MRI/PET/DTI modalities. The task is to link each image to a correct modality (1-A, 2-B, etc.) and motivate shortly your choice (e.g. how different tissues look like).



(1) (2) (3) (4)

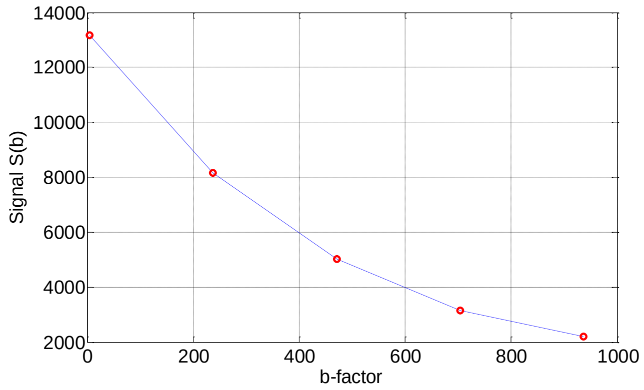
(A) T1-weighted
(B) T2-weighted
(C) PET
(D) Fractional Anisotropy
(E) Diffusion Tensor
(F) PD-weighted - Proton Density

(5 p)

Question 2 – Diffusion Tensor Imaging (DTI) and Brain Imaging (20 p)

(a) In a Diffusion Tensor Imaging (DTI) experiment we have measured the following points in individual pixels:

b-factor $[s/mm^2]$	S(b)
5	13168
238	8160
471	5030
704	3140
937	2210
...	...



(1) Perform a least-square fit with a monoexponential function $S(b) = S_0 \cdot exp\,(-b \cdot D)$ for b-factors (b) equal 5, 471 and 937 (i.e. using three data points). Use the logarithm of the signals to fit a linear function.
D stands for diffusion coefficient, S_0 is non-diffusion weighted signal, S is diffusion weighted signal.

(7 p)

(2) Plot the found function (with the estimated parameters S_0 and D) in a logarithmic y-scale.

(2 p)

Hint 1: The least-square solution to linear system equation $\boldsymbol{b} = \boldsymbol{A} \cdot \boldsymbol{x}$ can be found by
$\boldsymbol{x} = (\boldsymbol{A}^T \cdot \boldsymbol{A})^{-1} \cdot \boldsymbol{A}^T \cdot \boldsymbol{b}$

Hint 2: $\begin{bmatrix} 3 & -1413 \\ -1413 & 1099835 \end{bmatrix}^{-1} = \begin{bmatrix} 0.8441 & 0.0011 \\ 0.0011 & 0.0000 \end{bmatrix}$

(b) In an another diffusion experiment we have estimated the diffusion tensor as

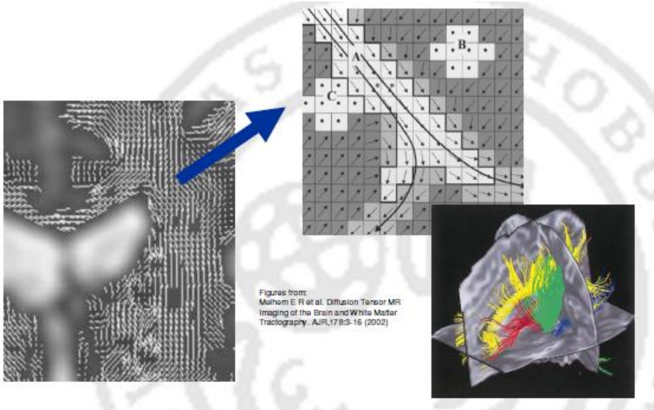
$$\boldsymbol{D} = \begin{bmatrix} a & 0 & 0 \\ 0 & a & 0 \\ 0 & 0 & a/2 \end{bmatrix}$$

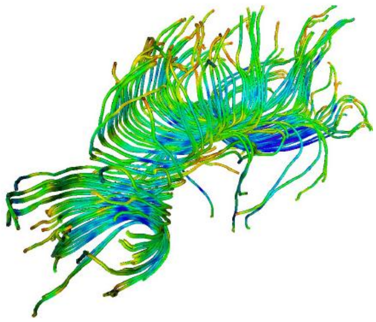
where a stands for some value. Visualize this tensor as an ellipsoid with proper axes, and calculate the mean diffusivity (the trace of the diffusion matrix divided by three).

(3 p)

(c) explain how DTI may be used for fibre tracking in the human brain

(4 p)





Brain tissue segmentation

(a) A segmentation algorithm #1 shows Jaccard Index = 0.8 for some region/tissue, and algorithm #2 shows Dice Index = 0.8 for the same region/tissue. Which algorithm shows a better segmentation performance? Motivate your answer.

(4 p)

Hint: The Dice score is equal $2V_{ae}/(V_a + V_e)$, where V_{ae} denotes the number of voxels that are assigned to tissue by both the automated algorithm the ground truth, V_a and V_e denote the number of voxels assigned to tissue by the algorithm and the ground truth, respectively.
The Jaccard index (J) is related to Dice index (D) by $J = D/(2 - D)$.

Question 3 – Microwave Tomography, Ultrasound, Nuclear Medicine (20 p)

Microwave Tomography

a) Describe and discuss pros and cons with the microwave diagnostic technology. What are the advantages with this technology? What are the challenges? Also compare and contrast the advantages and disadvantages with microwave imaging to CT-imaging, and Ultrasound.

(5 p)

b) In the course we have discussed three different methods for microwave image reconstruction. Which algorithm is most useful for imaging a body with many high contrast objects? Describe the main principles for this algorithm. Describe with words and draw pictures or flowcharts if it helps explaining. What are the challenges in reconstructing accurate images?

(5 p)

Ultrasound

Describe the main principles for generating A-, M- and B- mode ultrasound images.
What are the similarities and differences? In what situations are the different modes useful?

(5 p)

PET and SPECT

(a) explain what PET, SPECT stands for

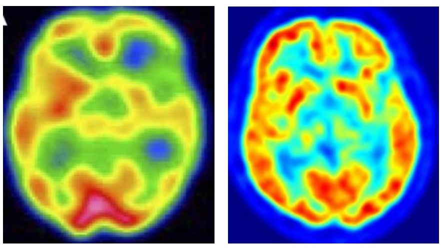
(1 p)

(b) describe the main physical principles, i.e. how PET/SPECT images are generated

(3 p)

(c) compare PET vs. SPECT with respect to cost (money), image resolution, equipment and tracers

(2 p)



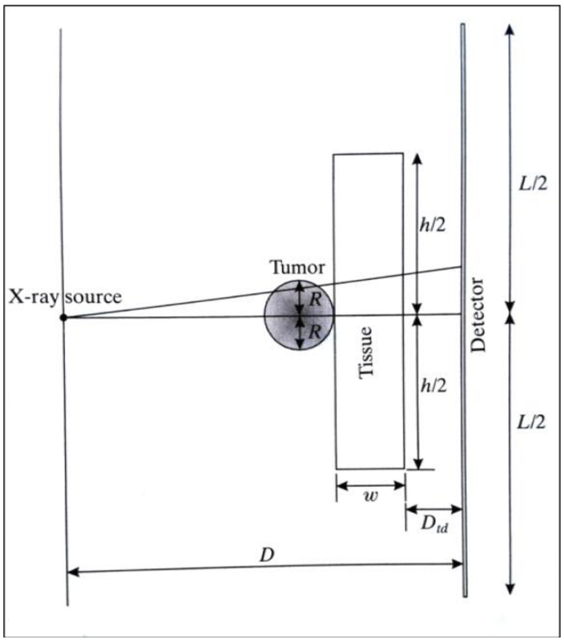
Question 4 – Radiography / Computed Tomography (20 p)

Radiography (physics and projection)

(a) Consider the x-ray projection radiography system shown in the figure below. Relevant dimensions in the figure are $L = 1\ m$, $D = 4\ m$, $w = 1\ cm$, $h = 3\ cm$, $R = 0.1\ cm$, and $D_{td} = 10\ cm$. **NOTE: See the Appendix for formulae, equations, etc.**

A contrast agent is used to enhance the image of the tumour. Assume a 35 keV (monochromatic) x-ray source and the linear attenuation coefficients given in the table below.

	μ - Linear Attenuation Coefficient (cm^{-1})	
Energy (keV)	Tissue	Tumour with Contrast Agent
35	2	6



(i) Assume that x-ray photons pass through the system in a straight line (from x-ray source to the centre of the detector). What percentage of these photons will be absorbed by the system?

(5 p)

(ii) The K-shell energies of **iodine** and **barium** are 33.2 keV and 37.4 keV, respectively. Assuming that either agent could be made into a compound that would go to the tumor, what would be the best agent to use and why?

(2 p)

(iii) Describe how the X-rays are generated and the **two** main sources/types (physics) of X-ray radiation.

(3 p)

Computed Tomography

a) Describe in detail the principle for the Filtered Back Projection algorithm. Describe with words (use pictures or flowcharts if you need) the different steps that are necessary in order to reconstruct the image, originating from the projection data, i.e. the sinogram.

(5 p)

b) Write down a mathematical expression for the Filtered Back Projection algorithm. Describe the different variables to such an extent that it would be possible to implement this equation based on the information you provide in the same way as you did in the CT-imaging project.

(5 p)

Question 5 – Future / Other Modalities (20 p)

Ultra-low field MRI (ulf-MRI)

1. Why is ~1 millitesla (1 mT or 1×10^{-3} T) an important threshold in ulf-MRI in regards to:
   a) Imaging contrast
   (2 p)
   b) Sensor technologies (i.e. SQUIDs vs. coils)
   (2 p)

2. Why can ulf-MRI potentially be better than modern/conventional/standard MRI
   (1 p)

Magnetoencephalography (MEG)

1. Why is MEG superior to functional MRI (fMRI) in terms of temporal resolution?
   (2 p)
2. Why could it be advantageous to perform MEG far from cities (that is to say, far from tram and automobile traffic)?
   (2 p)
3. Why does hand flexion/relaxation generate a significant change in MEG signal power (at 8-12 hertz (Hz)) as recorded from the sensorimotor cortex?
   (1 p)

Tomosynthesis

(a) Describe (very) shortly the principle of tomosynthesis.

(2 p)

(b) What are advantages and disadvantages of tomosynthesis, compared to other similar techniques (at least 2 advantages/2 disadvantages).

(2 p)

(c) Mention at least three clinical application areas of tomosynthesis.

(1 p)

Maximum intensity projection

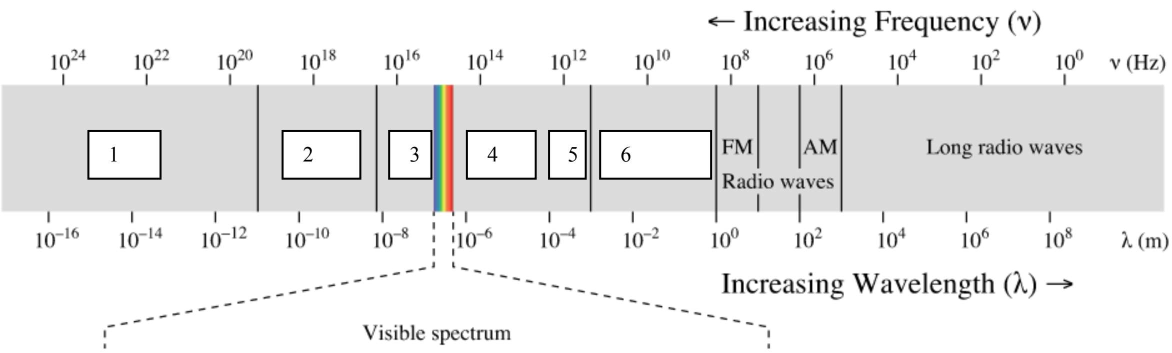
Calculate maximum intensity projection in direction of 45 degrees for the 2D image (size 3x3 pixels) below. The pixel size is 1 mm x 1 mm and the distance between pixels in the projected image should be 1 mm.

7	8	9
6	5	4
1	2	3

(3 p)

Electromagnetic spectrum

The figure below shows the electromagnetic spectrum and the names of the different bands are listed below the figure. Your task is to match the band with its' name, e.g. 1-a, 2-b, ...



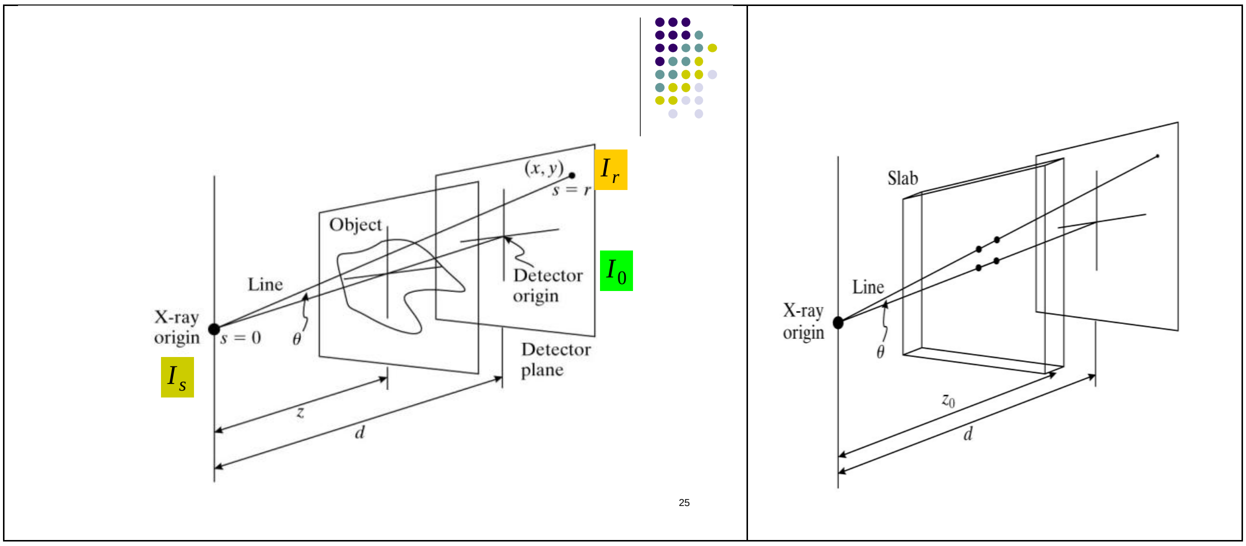
(a) infrared
(b) THz
(c) gamma-rays

(d) ultraviolet
(e) microwave
(f) X-rays

(2 p)

--- END (of questions)

APPENDIX – Geometric effects associated with x-ray image formation



where
I_0 - beam intensity at the origin of the detector
I_r - beam intensity at distance r from the origin of the detector
d - distance between the x-ray origin and the detector plane
r - distance between the x-ray origin and the detector point (x,y)
L - slab thickness
μ - a constant linear attenuation coefficient

Inverse Square Law	$I_r(x,y) = I_0 \frac{d^2}{r^2} = I_0 \cos^2(\theta)$
Obliquity	$I_r(x,y) = I_0 \cos(\theta)$
Path Length	$I_r(x,y) = I_0 \exp\left(-\mu \cdot L/\cos(\theta)\right)$

The fundamental photon attenuation law for the monoenergetic case:

$$I_{out} = I_{in} \exp(-\mu \cdot \Delta x)$$

where I_{in} is the intensity of the incident beam, Δx is the thickness of the slab of material, I_{out} is the beam intensity after passing through the slab, and μ is a constant linear attenuation coefficient.

END OF PAPER